Five-year Strategic Plan

Brookhaven National Laboratory

Center for Functional Nanomaterials

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EXECUTIVE SUMMARY

The Center for Functional Nanomaterials (CFN) is a Nanoscale Science Research Center operated for the U.S. Department of Energy (DOE) at Brookhaven National Laboratory (BNL). As a national scientific user facility, the CFN mission is to empower nanoscience research, by providing essential capabilities and technical expertise, achieving breakthrough discoveries through internal research, and rapidly adapting to evolving national research priorities. CFN strategy emphasizes *adaptiveness*, such that we impact current national initiatives, and *acceleration*, where we empower the community to innovate more rapidly.

The CFN is delivering major impacts in areas of national interest, including quantum information science and technology (e.g., one-of-a-kind platform for automated heterostructure fabrication), microelectronics (e.g., hybrid materials for next-generation lithography), energy materials (e.g., operando studies of catalysts), transformative manufacturing (e.g., integrated self-assembly), and AI/ML (e.g., AI assistant at x-ray beamline).

The CFN is able to rapidly and smoothly adapt to the evolving needs of national priorities and the broader materials research community, by investing strategically in coherently-defined thematic areas.

- *Nanomaterial Synthesis by Assembly:* Design strategies for synthesis of new materials with targeted functionality by assembly of nanoscale components, for rapid explorations of vast landscapes of complex structural motifs. CFN research on self-assembly devises new approaches to interaction- and process-controlled assembly of components, discovers the governing principles underlying self-assembly, and understands assembly pathways using advanced characterization and computational methods. CFN is leading in the development of automated synthesis-by-assembly approaches. Our ultimate goal is to enable inverse design of nanomaterials, leveraging understanding of nanoscale components, processing effects, structural design, and device integration.
- *Quantum Nanomaterials:* Investigates how quantum phenomena emerging at the nanoscale, such as collective excitations, topological states, correlated phases, coherence or entanglement, can be controlled to enable next-generation quantum technologies. The ultimate goal is to guide the assembly of nanomaterials and devices that can provide programmable quantum states by design. CFN research encompasses superconducting thin films, 2D van der Waals layers, correlated crystals, and functional quantum devices such as quantum emitters and circuits. By integrating precise materials synthesis with multimodal microscopy and spectroscopy across a wide spectral and temperature range, from microwaves to x-rays and from room temperature to the millikelvin regime, combined with modeling of lattice, charge, orbital and spin degrees of order, the CFN seeks to uncover the fundamental principles that govern quantum functionalities in nanomaterials.
- *AI-Accelerated Nanomaterial Discovery:* Implement artificial intelligence and machine learning (AI/ML) to streamline the material synthesis-characterization-analysis loop. While historically the discovery and development of new materials has followed an iterative process of synthesis, measurement, and modeling, suitable integration of advanced characterization, robotics, and machine-learning can potentially radically accelerate this process. The CFN has an established record of discovering nanomaterials by applying new materials synthesis strategies, advanced characterization, and machine-

learning. Integrating these efforts will enable autonomous platforms for iteratively exploring material parameter spaces, which have potential to revolutionize materials science by uncovering fundamental links between synthetic pathways, material structure, and functional properties. The CFN is aggressively pursuing frontier AI technologies (including large language models and agentic motifs) to empower next-generation science campaigns. CFN envisions a Science Exocortex wherein researchers leverage a swarm of AI agents that operate as a coherent whole, allowing the human to undertake more ambitious science.

- *Multimodal Analysis of Nanomaterials in Operando Conditions:* Accelerates research by monitoring materials, via multiple probes, in their operating environments. Interrogating materials at the nanoscale to derive atomic-level information on physicochemical processes under operating conditions remains a forefront and evolving nanoscience research field. The CFN will augment its comprehensive suite of instruments for operando studies of nanomaterials such as catalysts, photocatalysts, and battery electrodes. The CFN will increasingly integrate operando capabilities with data management and computational resources for advanced AI-accelerated data analytics.

The CFN strategic plan is grounded in foundational pillars of an expert staff, an engaged user community, and a collection of strategic partners — all working safely and supported by excellent operations and a portfolio of state-of-the-art capabilities. The CFN is working toward higher levels of user engagement and a broader pool of users, through strategic partnerships with larger initiatives aligned with national initiatives, technical workshops customized to communities with specialized needs, and by visibly promoting user science accomplishments. During the next five years, the CFN will invest in new instrumentation, make major upgrades to distinctive capabilities, and develop new data-analytics and data-management methods to maintain its status as a cutting-edge user facility.

A high priority is continuing to enhance the partnership between CFN and NSLS-II, through: investing further in partner x-ray nanoscience instruments; working together to identify opportunities to create unique, new capabilities; and advancing joint projects with NSLS-II staff and users that exploit the complementary properties of x-rays and electrons to collect multimodal information on the same samples.

1. MISSION AND VISION

The Center for Functional Nanomaterials (CFN) is a state-of-the-art nanoscience facility with the dual mission of enabling the research of external users and leading transformative basic research to discover, understand, and implement nanomaterials. The combination of scientific staff expertise, portfolio of distinctive nanoscience capabilities, engaged community of users, and strong partnership with the National Synchrotron Light Source II (NSLS-II) at BNL, make the CFN unique among nanoscience centers worldwide.

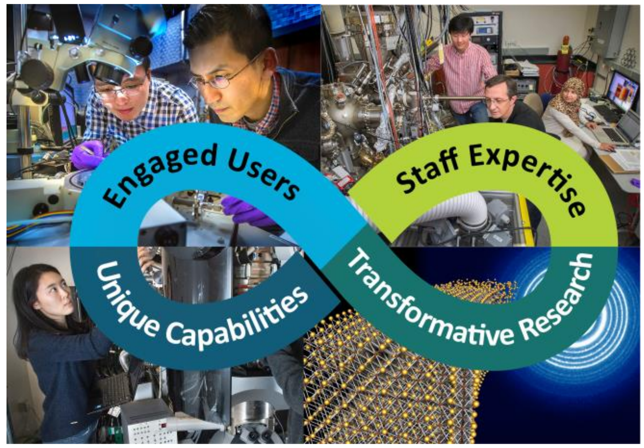

Figure 1. CFN users and expert staff collaborate, making use of unique capabilities to address complex scientific questions and technological challenges in nanoscience. The staff is recognized for international leadership in self-assembled nanomaterials, X-ray scattering, and quantum heterostructures, among other areas. Advanced CFN capabilities in operando probes, aberration-corrected electron microscopes, and robotic synthesis tools stand out.

The CFN is focused on delivering on the mission of the Department of Energy's Office of Science. To that end, CFN strategy emphasizes *adaptiveness*, such that we impact current national priorities, and *acceleration*, where we empower the community to innovate more rapidly.

2. IMPACTS

The CFN empowers the research programs of a wide variety of academic and industrial scientists (>740 users supported in 2025), who are studying the frontiers of nanoscience. CFN's strategy of investing in diverse and unique science facilities, and employing leaders across a range of frontier nanoscience subject areas, enables the CFN to have impact on emerging material science topics, even as the topics of interest evolve over time. This has allowed the CFN to deliver impactful research in areas of current critical need to the nation, especially:

- **Quantum Information Science and Technology (QIST):** CFN stewards one-of-a-kind synthesis platforms (notably QPress, for automated heterostructure fabrication) and advanced characterization tools (including photoemission microscopy and femtosecond spectroscopy) relevant to quantum materials. This program has delivered numerous advances, including elucidation of processing effects in fabrication of tantalum resonators, currently the most promising material for high-performance superconducting qubits.
- **Microelectronics:** CFN's longstanding expertise in self-assembled nanomaterials and hybrid (organic/inorganic) material synthesis have been applied, over the last several years, to frontier challenges in microelectronics and next-generation computation. Of particular note, CFN's expertise in infiltration synthesis to form hybrid materials enabled the rapid demonstration of new material classes well-optimized to act as photoresists for frontier extreme ultraviolet (EUV) lithography. This work responds directly to pressing industrial needs for new, tunable materials as lithography pushes into ever more stringent regimes.

- **Energy Materials:** The DOE has longstanding interests in materials that underlie energy generation, transformation, and storage; with a growing emphasis on identifying solutions sensitized to the nation's critical materials needs. The CFN stewards a portfolio of advanced characterization tools, including multimodal microscopy and spectroscopy tools that can probe materials under in situ and operando conditions, optimized to understand materials mechanistically, enabling rational design of material tradeoffs.
- **Critical Materials:** The CFN is poised to deliver impact to this emerging national priority. CFN expertise in separation science (e.g., membranes, atomic capture), efficient material usage (especially in catalysis), and advanced characterization (especially multimodal operando) will be deployed to advance projects that maximize the efficient use of scarce materials and seek to identify alternatives for functional materials.
- **Transformative Manufacturing:** The DOE Office of Science recognizes the importance of long-horizon basic research that could evolve into future manufacturing paradigms. The CFN is a leader in synthesis-by-assembly methods, wherein nanoscale components are organized into new materials. For instance, CFN leadership in exploiting DNA as a programmable nanoscale component has led to landmark demonstrations of novel nanomaterials, including formation of elusive diamond motif, and integration of designed self-assembled superlattices with top-down lithographic device arrays.
- **Artificial Intelligence and Machine-Learning (AI/ML):** CFN has longstanding leadership in demonstrating autonomous experimentation (AE), including landmark demonstrations of autonomous x-ray scattering, and in the application of ML to spectral analysis. The CFN is now at the forefront in the application of large language models (LLMs) and agentic AI to science, including having demonstrated an AI assistant for synchrotron beamline control.

CFN expects national priorities to evolve over time; and rapidly so, given the breathtaking advances currently being witnessed in the areas described above. That being the case, CFN strategy is fundamentally focused on maintaining a coherent portfolio of frontier tools and world-leader researchers, such that we can rapidly pivot towards demonstrable impact in new topic areas, as they arise. The CFN has a longstanding history of delivering on this paradigm. We routinely adapt our skills to new user topics (which change constantly), have invested in topics of national interest (e.g., QIST), and have often been ahead of the national trends (e.g., developing AI for science for over 14 years). Going forward, the CFN expects to rapidly update our impact area foci, leveraging an underlying strategic planning process that is coherent and deliberate.

3. EXECUTION

Mission success rests on the expertise of the CFN staff and the state-of-the-art nanoscience capabilities they develop and operate. To execute on the CFN mission of adapting to impact national priorities, the CFN employs strategic themes that guide our investments to be coherent, diverse, and adaptive.

- Nanomaterial Synthesis by Assembly
- Quantum Nanomaterials
- AI-Accelerated Nanomaterial Discovery
- Multimodal Analysis of Nanomaterials in Operando Conditions

3.1 Theme 1: Nanomaterial Synthesis by Assembly

Synthesis-by-assembly, in contrast to traditional synthesis by covalent bond formation, seeks to create new materials by organizing nanoscale components. This approach opens a vast combinatorial space of new materials, drawing from a broad library of nano building blocks and selecting among a rich set of structural architectures. CFN is a leader in fundamental research into nanomaterial synthesis-by-assembly, enabling rapid development of new multiscale and multicomponent materials to deliver on national priorities in advanced manufacturing, information processing, and microelectronics. CFN work encompasses nano-synthesis, self-assembly, and processing approaches, including additive manufacturing and templating, as well as hybrid strategies that integrate top-down and bottom-up methods. Advances in chemical, polymeric, and biopolymer synthesis have produced an extensive palette of structurally diverse and property-tunable nanoscale components, from engineered nanoparticles, polymers, and supramolecular complexes to designed proteins and DNA nanoarchitectures. Longstanding CFN leadership in self-assembly has revealed governing principles, and established conceptual and practical foundations for constructing prescribed nanomaterials. Our long-term objective is to realize an inverse design framework that explicitly defines synthesis and assembly routes to produce desired structures with target functionality.

CFN research encompasses the creation of diverse nano components, including nanoparticles, DNA and biomolecular complexes, polymers, zeolites, and 2D materials; as well as their integration into larger-scale systems. Examples include nanoparticles with defined shapes and atomic structures, biomolecule-directed assemblies with unique optical and chemical responses, block-copolymer systems for modulating surface and mass transport properties, and nanoparticle assemblies that address challenges in catalysis and energy transfer. Additionally, inorganic materials are templated from nanoscale soft scaffolds for applications in mechanics, sensing, and information processing.

The CFN will accelerate the science of synthesis-by-assembly by embedding these synthesis capabilities within robotic platforms and autonomous experimentation environments (Figure 2).

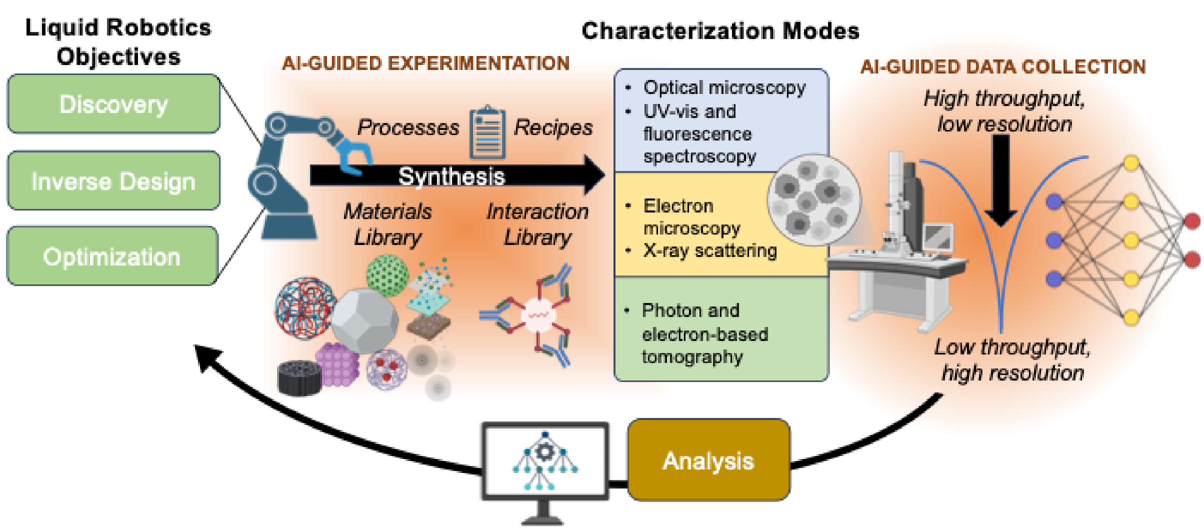

Figure 2. Advancing material design and fabrication through AI-guided robotic synthesis and assembly platforms with autonomous experimentation environments and multimodal characterization capabilities.

Robotic liquid handling supports synthesis and characterization across nano- to macroscales. Standardized methodologies and curated material libraries will interface seamlessly with AI-guided synthesis algorithms, enabling transformative progress in: (1) discovery of new phenomena through rapid exploration of vast design spaces; (2) inverse design of materials to generate targeted functional performance; and (3) optimization of protocols to enhance synthesis fidelity, reproducibility, and throughput, while extending synthesis-by-assembly to entirely new classes of materials.

This effort relies on cutting-edge characterization, including x-ray scattering, electron microscopy, single-molecule optical detection, ultrafast micro-spectroscopy, and photon- and electron-based tomography. Ultimately, we will integrate in situ characterization into the synthesis process for real-time structure and property monitoring and feedback.

Over the next five years, CFN will focus research on:

- Rational design and synthesis of nanoparticles with targeted functions by controlling their shape, size, and composition. Using substrate-guided assembly, complex nanoparticle lattices will be fabricated and manipulated to achieve controllable collective optical, magnetic, and catalytic properties.
- Versatile modeling and design tools for realizing rational nanomaterial assembly. Numerical simulations will be used to understand structure formation, enabling guided kinetic pathways for high-fidelity self-assembly.
- Liquid handling robotics for automated fabrication by assembly, integrating DNA-based assembly platforms with component libraries and rapid on-deck characterization.
- Co-design of polymer formulations and processing to realize hierarchical, self-assembled architectures with unique morphologies and unprecedented functionality. For example, precision-formulated block copolymer/homopolymer blends can be directed to assemble into defect-free nanolithography patterns or hybrid polymer-inorganic nanoporous membranes.
- Establishing domain-science benchmark systems (nanoparticle synthesis, DNA-, peptide-based, and block copolymer self-assembly) that serve as testbeds for validating the complete autonomous workflow from hardware (robotic liquid handlers and droplet flow reactors) to software (real-time data collection, automated analysis pipelines, AI-driven optimization, visualization tools), enabling systematic refinement and community adoption.
- Developing adaptive multi-resolution experimental strategies that use low-cost, low-resolution measurements (UV-Vis, DLS, optical microscopy) to intelligently guide deployment of high-resolution, high-cost characterization (SAXS/WAXS, TEM, tomography, coherent x-ray imaging). This maximizes information accrual while minimizing experimental resources.
- Controlling non-equilibrium synthesis pathways through reinforcement learning by implementing rapid, dynamic control of reaction conditions (temperature cycling, reagent pulse injection, flow rate modulation) to unlock kinetically trapped structures and novel assembly motifs inaccessible through traditional synthesis.
- Decoding reaction mechanisms through theory-guided closed-loop workflows where mechanistic models (nucleation/growth theories, kinetic simulations) guide AI to propose maximally informative experiments.
- Inverse design of target structures and properties, by developing assembly algorithms and autonomous platforms that learn inverse mappings from desired structural motifs (e.g., hierarchical organization, nanoscale architecture and porosity, topology of nanoscale

connections) or emergent properties (e.g., chiral optical response, chemical activity, mechanical properties) to optimal synthesis-by-assembly protocols.
- Developing inorganic templating methods and applying them to complex, self-assembled bio/polymer/inorganic scaffolds, for control over composition and design of nanomaterials.

To advance these ambitious plans, new methods and capabilities (Figure 3) will be developed:

- In situ, time-resolved, x-ray scattering for quantitative descriptions of ordered, weakly ordered, and cluster nanoscale systems, at size scales ranging from one to 100s of nanometers, and timescales as short as milliseconds.
- Micro-beam synchrotron scattering for phase mapping of nanostructured multi-component materials across scales, from molecular to macroscopic.
- Multiscale 3D imaging, including lab- and synchrotron-based x-ray imaging and electron microscopy methods, to quantify fabrication scaling, defects, and operando performance. These methods will combine 3D structural, chemical, and stimulus-dependent (through reactions, stresses, and external fields) information.
- A modular robotic thin film synthesis platform for high-throughput autonomous workflows, to explore high-dimensional parameter spaces, streamline complex process optimization, facilitate robust data and metadata collection, and train AI agents for autonomous synthesis.
- Ultrafast and single-molecule optical methods to probe local optical fields, carrier and energy transfer and transduction processes, polarization signatures, chirality and materials heterogeneity.
- Physics-informed digital twin that integrates mechanistic models (classical nucleation-growth theory, coarse-grained molecular dynamics, phase-field simulations) with machine learning corrections, continuously learning from experimental feedback to enable real-time prediction of synthesis outcomes, adaptive parameter exploration, and iterative model refinement throughout the synthesis process.

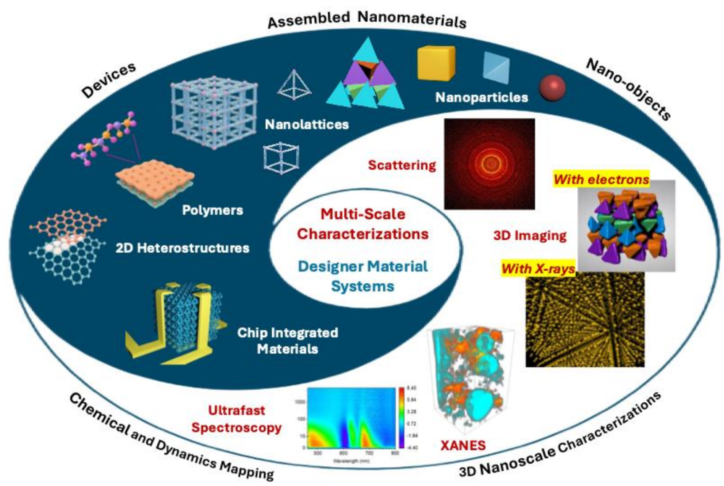

Figure 3. Integrating multiscale characterization capabilities for guiding discovery and fabrication of different classes of synthesized and assembled nanomaterials.

The development of AI-guided synthesis-by-assembly and multimodal in situ characterization will enable us to establish a distributed network of standardized autonomous synthesis platforms, and thus a “virtual lab” for material synthesis, where researchers can remotely perform experiments, access diverse characterization capabilities, contribute to a centralized knowledge base, and collectively train AI models. CFN will transition nanomaterials discovery from isolated laboratory efforts into a coordinated national platform.

3.2 Theme 2: Quantum Nanomaterials

A wide range of quantum phenomena arise at nanometer dimensions, giving nanomaterials unique functionalities that underpin emerging quantum technologies. In two-dimensional (2D) materials and heterostructures, quantum confinement and electronic correlations lead to exotic states and emergent phases such as correlated insulators, unconventional superconductivity, magnetism, and nontrivial topological phases. In superconducting nanomaterials and devices, macroscopic quantum coherence provides the foundation for robust quantum bits (qubits) and scalable quantum computing. Quantum light-matter interactions across a broad spectral range, spanning microwaves to x-rays, enable advanced microscopy and spectroscopy techniques that probe the quantum electronic, magnetic, and chemical functionalities of nanomaterials. Realizing these opportunities requires precisely engineered nanomaterials, comprehensive characterization tools and modeling. As an emerging leader in quantum nanoscience, the CFN integrates capabilities in precise nanomaterial fabrication, multimodal microscopy, advanced spectroscopy, and theory to provide the tools and expertise needed to explore, manipulate, and exploit quantum functionality in nanomaterials.

The CFN has deep expertise in the precise fabrication and processing of quantum nanomaterials, including atomically flat 2D heterostructures, epitaxial superconducting thin films, and functional devices. A flagship capability is the Quantum Material Press (QPress), a modular, automated platform that enables deterministic fabrication and processing of 2D and Moiré heterostructures with atomic-layer precision. The CFN's nanomaterial synthesis and processing tools, together with complementary facilities for advanced electron microscopy, synchrotron-based x-ray microscopy and spectroscopy, ultrafast optical spectroscopy, and low-temperature electronic transport characterization, provide means to link material structure with emergent quantum functionalities. A notable example is the CFN's user support for the Brookhaven-led Co-Design Center for Quantum Advantage (C2QA), a DOE hub established under the National Quantum Initiative (NQI), where CFN capabilities are essential for correlating material properties with the decoherence of superconducting qubits, contributing significantly to C2QA's ongoing success.

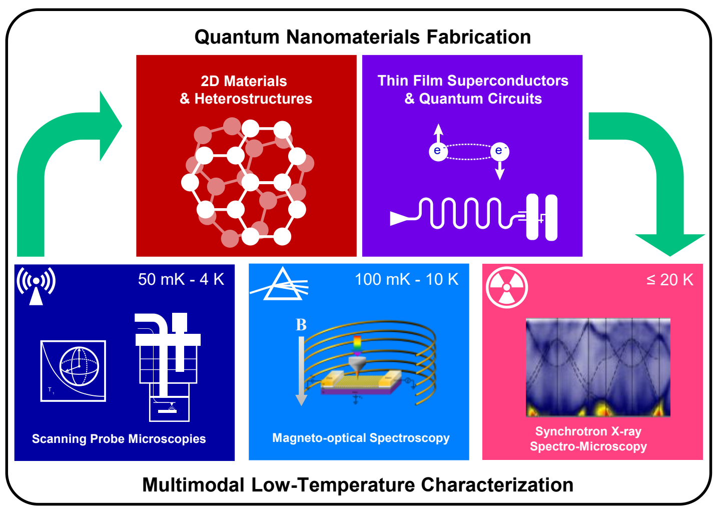

Figure 4. Integrated platform for quantum nanomaterials.

Many intriguing quantum phenomena emerge near the material's ground state, where thermal fluctuations are suppressed and quantum degrees of freedom can be manipulated by strong electromagnetic fields. Accessing these regimes requires extremely low temperature and high-field environments. The CFN has expanded its experimental capabilities, assembling a suite of tools for characterization of quantum nanomaterials under these extreme conditions. The physical property measurement system (PPMS) enables electrical transport and magnetism measurements of quantum nanomaterials at temperatures below 1 K and under magnetic fields up to 12 T. The Integrated Platform for Quantum nanoMaterials (IP-QM) (Figure 4) combines complementary capabilities for correlated studies, including ultrafast magneto-optical confocal microscopy for probing carrier and exciton dynamics in 2D heterostructures and quantum emitters, x-ray photoemission electron microscopy (XPEEM) for electronic, magnetic, and chemical imaging, and quantum-sensor-based scanning probe microscopies (SPM) for atomic-scale potential mapping and single-spin detection, all operating at cryogenic temperatures. The CFN combines the synthesis and exploration of quantum nanomaterials with theory and modeling. First-principles theory is used to understand the impact of interface properties, such as symmetry breaking, strain and charge transfer, on the emergent quantum states. Together with the model Hamiltonian approach and phenomenological theory, our approach can unravel the interplay of symmetry, topological states, spin-orbit coupling, and superconductivity.

Looking ahead, the CFN will extend its characterization capabilities for quantum nanomaterials into the millikelvin regime ($\leq$ 100 mK) to directly probe emergent quantum phases and identify material limits to improve coherence in superconducting qubits and other quantum devices. New device characterization, microwave spectroscopy, high spectral resolution STEM, and SPM capabilities at millikelvin temperatures will provide unprecedented insight into the topological order, correlated quantum coherence, and decoherence mechanisms that define nanomaterials device functionality. These capabilities will be integrated with existing cryogenic tools within IP-QM to form CFN's low-temperature quantum characterization framework, enabling direct observation and control of quantum phenomena with technological relevance and establishing the CFN as a national resource for the discovery and understanding of quantum functionalities at the lowest temperature limits.

During the next five years, CFN scientists and users will investigate a variety of quantum functionalities of nanomaterials, especially:

- Optimizing superconducting nanomaterials for scalable, silicon-compatible qubits, focusing on transition-metal silicide platforms that enable high coherence and monolithic integration.
- Probing the microscopic origins of the loss channels that limit coherence in superconducting circuits, through millikelvin microwave spectroscopy and impedance microscopy.
- Developing atomically engineered 2D materials to control correlated quantum coherence arising from strong electron-electron and electron-hole interactions. This will leverage topological protection and quantum coherence for next generation quantum and energy-efficient electronic devices. Examples include superconductors, exciton condensates, and Chern insulators that exhibit phase coherent and low-loss transport.
- Investigating interlayer interactions in epitaxially grown heterostructures of graphene-like 2D materials to understand energy and charge coupling mechanisms that govern their quantum and optoelectronic functionalities.
- Discovering new topological superconductivity material platforms based on the 2D van der Waals assembly, combining the unique QPress and IP-QM facilities with theory and modeling.

CFN scientists will advance quantum characterization instrumentation by:

- Completing commissioning of the cryo components from IP-QM facilities that integrate:
    - A synchrotron, cryogenic XPEEM for electronic, magnetic, and chemical imaging;
    - A magneto-optical confocal microscope for carrier and exciton dynamics in quantum emitters and 2D heterostructures; and
    - A quantum-sensor SPM for atomic-scale potential mapping and single-spin detection.
- Establishing a new suite of millikelvin characterization tools:

- A continuous adiabatic-demagnetization refrigerator (cADR) for rapid, high-throughput screening and prototyping of quantum electronic devices;
- A dilution-refrigerator-based SPM for microwave impedance microscopy and scanning resonator microscopy; and
- A dilution-refrigerator-based magneto-optical microscope for millikelvin optical spectroscopy and quantum transport measurements of functional low-dimensional materials that exhibit strongly correlated and topologically protected quantum states.

We take as our ambitious, long-term goal to advance quantum science into the regime where we can deliver programmable quantum states by design. Emerging materials systems such as superconducting circuits and 2D van der Waals layers have opened avenues for the design of exotic quantum states with excellent tunability. Being programmable requires manipulation of the quantum states with greater precision, which motivates deeper understanding of noise sources and associated nanoscale complications. We will tackle these challenges by advancing synthesis and characterization techniques adapted to quantum nanomaterials. As an example of this approach, we will design and engineer materials that show quantum anomalous Hall effect at elevated temperatures.

3.3 Theme 3: AI-Accelerated Nanomaterial Discovery

Modern materials are increasingly complex. Formed from a wide range of components, they exhibit structural order at multiple length scales (atomic, molecular, nano, meso, micro, macro) and are synthesized using elaborate processing pathways, frequently in non-equilibrium states. The functional demands on new materials are increasing, designed for performance improvements in next-generation applications. Historically, new materials development has followed an iterative process of synthesis, measurement, and modeling. Tightening this discovery loop has potential for radically accelerating the design of new materials and revolutionizing materials science. The CFN is among the leaders in developing next-generation methods for accelerated nanomaterial discovery, including combinatorial sample libraries, robotic synthesis, advanced characterization, machine-learning analytics, and autonomous experimentation platforms that iteratively explore material parameter spaces and uncover fundamental links between synthetic pathways, material structure, and functional properties.

Artificial intelligence and machine-learning (AI/ML) methods are advancing at a staggering pace, poised to revolutionize cognitive work. This represents an unprecedented opportunity for nanoscience. The CFN is playing a leading role in demonstrating how ML models and frontier agentic AI can empower more ambitious physical science research. The CFN will build towards a science exocortex—a swarm of AI agents operating in unison to extend a researcher's cognition and volition (Figure 5). Beyond merely accelerating tasks, the exocortex will be an extension of a person's cognition (memories, thoughts, intents), by frictionlessly surfacing novel trends and ideas, and translating scientific ideas into autonomously executed research directions.

The development of the envisioned exocortex requires frontier methodological research and adaptation of AI/ML methods to nanoscience research. The proposed architecture for the exocortex reveals a set of research drivers:

- *What are the best ways to connect researchers to automated synthesis, characterization, and computational modeling platforms?* The CFN has expertise in developing automated research

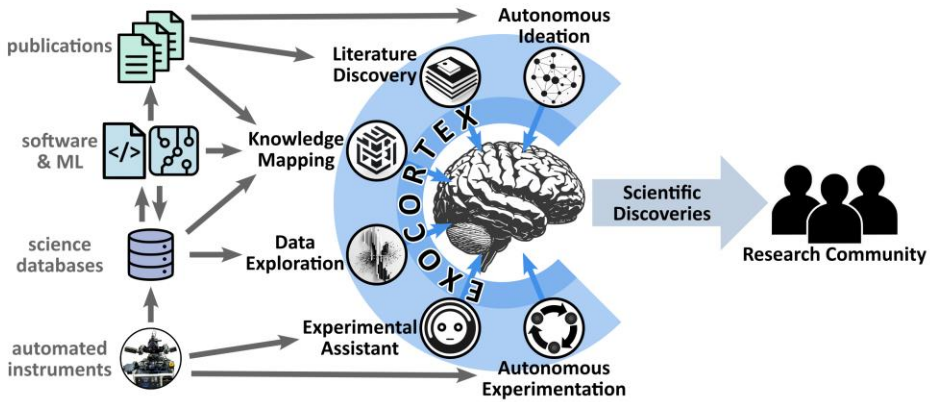

Figure 5. A science exocortex extends the researcher's cognition and volition, by mediating activity through a swarm of AI agents. These agents leverage foundation models (e.g., for language, code, decision-making) to perform tasks such as autonomous experiments, streamline interaction with information (datasets, publications), and enable new ways of AI-human brainstorming. These AI capabilities will be built on top of intrinsically useful components, including: synthesis platforms, open databases, and ML-accelerated analysis code.

platforms and autonomous experimentation methods and is demonstrating the viability of AI language models for streamlined control of scientific instruments and simulations—using AI as an experimental assistant. The CFN will integrate and refine these capabilities to create low-friction interfaces with the researcher, for planning, launching, monitoring, and modifying complex experiments.

- *How can data streams be integrated into scientific knowledge?* Researchers gain scientific understanding by integrating disparate kinds of information into a coherent model in their minds. CFN will develop machine information synthesis, by combining multi-modal ML models with agentic control of analysis and simulation software.
- *How can scientist cognition be empowered?* Human scientists are expert in high-level knowledge synthesis and planning. CFN will research how to leverage multi-AI interaction for science tasks, and will deploy ecosystems of AI agents to empower scientists.

Realizing this vision requires advancements and automation of all stages of material discovery: synthesis, especially by implementing combinatorial libraries and real-time synthesis platforms; characterization, including multimodal in-situ/operando measurements; and understanding, through theory/analytics and use of machine-learning to drive experiments.

- *Autonomous Experimentation*: CFN will investigate improved algorithms for control of experimental platforms, including increasing integration of inputs from theory and simulation. We will leverage large language model (LLM) technology to build experimental assistants, which will provide streamlined control of complex instruments, including experiment execution, autonomous loops, and data analysis. We will deploy proven methods across a broad range of nanoscience instruments.
- *Synthesis Platforms*: The CFN has invested significantly in developing materials synthesis platforms, including the QPress, a photo-thermal annealer for thin film non-equilibrium physics, a spray deposition tool for adaptive synthesis of soft materials, a flow-reactor for nanoparticle synthesis, and a robotic liquid handler to automate voxel-assembly strategies of complex architectures using DNA self-assembly. The CFN will continue developing these and other platforms, targeting their use in accelerating the research loop. The CFN will

develop a modular robotic system for synthesis, processing, and characterization of thin film samples.

- *Modeling*: CFN will develop physics-based, AI-accelerated modeling workflows that connect experiments and computation. CFN will develop real-time analysis pipelines that map image/spectral data to underlying structure, *during* an experiment. We will provide web interfaces (e.g., lightshow.ai) to bring advanced, AI-driven characterization tools directly to users. By liberating staff and users from complex domain-specific analysis, these workflows will enable them to focus on the most challenging scientific questions. CFN will lead the development, adaptation, and fine-tuning of machine-learned interatomic potentials that are physically constrained and benchmarked, enabling fast, high-fidelity predictions of atomic structures, spectra, and functional properties in complex nanomaterials that are central to accelerated nanomaterial discovery.
- *Science Agents*: CFN will concretely design, test, and deploy infrastructure for advanced science workflows. We will exploit LLMs AI agents for autonomous ideation, hypothesis generation, and experimental planning. We will transition CFN experimental and simulation datasets into robust database environments and build ML-driven data exploration tools that provide nanoscience researchers with new ways to identify trends and outliers in their data. Science agents will orchestrate AI-coupled workflows, in which simulations and AI run side-by-side. These agents will be increasingly presented through web interfaces that integrate CFN tools and data, lowering the barrier for staff and users to adapt advanced AI/ML methods.

3.4 Theme 4: Multimodal Analysis of Nanomaterials in Operando Conditions

Many technologically important systems—catalysts, energy-storage materials, microelectronics, neuromorphics, and quantum materials—exhibit dynamic structural, chemical, and electronic responses that can only be observed under the conditions in which they operate. No single technique can probe the full complexity of modern materials, as all aspects of physical, chemical, and electronic structure are relevant to stringent functional requirements. For example, designing next-generation catalysts hinges on identifying active phases, intermediates, and reaction mechanisms, as they evolve under realistic pressures, temperatures, and environments (liquid or gas), spanning a broad range of time and length scales from atomic interactions to mesoscopic restructuring.

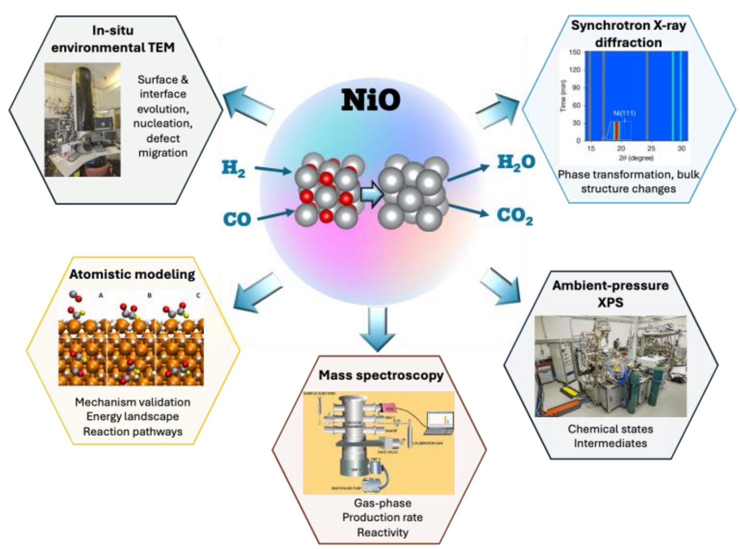

Figure 6. Frontier nanoscience research requires a convergence of measurement modalities, ideally studying materials under in-situ or operando conditions.

CFN has longstanding leadership in the integration of complementary in-situ and operando characterization tools for detailed, multi-modal studies. The CFN has assembled a comprehensive suite of in-situ, operando, and multimodal tools—spanning environmental and low-energy electron microscopy, reactor STM, AP-PES, IR/Raman spectroscopy, x-ray imaging and scattering, ultrafast optical probes, and a broad suite of specialized in-situ holders. CFN scientists and users leverage these advanced capabilities to address a wide range of materials science challenges, including heterogeneous catalysis under working conditions, photocatalysis and quantum-interface engineering, energy storage and conversion, and manufacturing. To further accelerate discovery, CFN is deploying ML-driven methods for rapid, quantitative interpretation of these increasingly complex datasets. The CFN is accelerating nanoscience by integrating these time-resolved techniques across x-ray, vibrational, and electron microscopy modalities and by coupling these measurements to atomic-scale simulations that connect observed spectra and structures to underlying physical mechanisms.

Over the next five years, CFN scientists will advance in-situ, multi-modal, and operando infrastructure and integrate them with other capabilities being developed at NSLS-II by:

- *Multimodal in-situ platforms for functional materials in reactive environments:* The CFN will develop increasingly complex, integrated characterization frameworks (digital and physical) that combine environmental TEM/STEM, AP-XPS, and reactor STM with synchrotron x-ray methods, along with corresponding techniques developments, such as quantitative tomography and fluctuation electron microscopy for characterizing amorphous materials. These platforms will enable direct visualization of dynamic structural and chemical transformations under controlled working conditions, thereby linking atomic-scale structure, local chemistry, and macroscopic functionality across a variety of materials, including catalysts, batteries, microelectronics, and quantum materials.
- *Machine-learning–assisted data analysis and autonomous experimentation:* The CFN will leverage AI/ML to handle and analyze on-the-fly multimodal datasets (TEM/STEM, XPS, XRD, Raman, etc.) and guide real-time adaptive in-situ experiments. These approaches will enable predictive, autonomous discovery of material transformations, dramatically improving experimental throughput and critical fundamental insights that are not available by ex situ methods alone.
- *Functional materials under reactive bias:* The CFN will probe materials where electronic, ionic, and structural responses are tightly coupled, with increasing focus on microelectronics and quantum materials. For example, the CFN will combine biasing TEM holders, AP-XPS cells, and operando synchrotron tools to study phase transitions, point defect dynamics, and charge redistribution in neuromorphic and semiconductors. These efforts will reveal new design rules for electronic, quantum, and catalytic materials central to microelectronics, quantum information science, and energy innovation initiatives.
- *Nano-Processing In situ:* By achieving the above multi-modal software-hardware infrastructure and by advancing capabilities for measurements in situ during processing, the CFN will uniquely enable observing nanomaterials as they nucleate, transform, and grow across the relevant length and time scales. The CFN will generate the foundational knowledge needed to resolve transient states, kinetics, reaction pathways, and nonequilibrium phase development. These mechanistic insights are essential for advancing synthesis and processing science that underpins next-generation quantum materials, microelectronics, and energy materials. By elucidating the principles governing nucleation, growth, and functional

evolution, this multi-modal and operando effort will transform the scientific basis and accelerate the design of functional nanomaterials.

4. PILLARS

Achieving the objectives of this strategic plan requires an expert staff, an engaged user community, and a set of strategic research partnerships. World-leading research by staff and users must be conducted safely and supported by both excellent operations and state-of-the-art facilities. Achieving our mission requires continued commitment to these essential pillars, as detailed here.

4.1 Safety and Operational Excellence

Excellence in operations and a strong safety culture are central to CFN success. The CFN emphasizes the importance of communication and training among the staff and users with diverse backgrounds and experiences as the best approach to achieving safety compliance. A robust operational and administrative infrastructure supports the research experience from concept to project completion. Safety is fully integrated into all aspects of the work. Regularly reviewed and updated course modules and on-the-job training are essential for safe and productive research. Prior to independent use of CFN facilities, every new user is trained in general and work specific operations and safety procedures. New users are paired with an expert mentor for guidance on operations, hazard identification, and response. Focus areas for operations and safety include:

- More tightly integrating safety standards and guidelines, operational procedures, and administrative support for planning and executing research;
- Implementing a project planning process to instrument acquisition, installation, commissioning, and operations that reduces and controls hazards;
- Continuously improving our team-oriented work planning and control process to enhance efficiency and safety in service and maintenance of CFN instruments;
- Developing a facility master space plan to guide new instrument installations and workspace allocation; acquiring lab space in other BNL complex buildings, as needed; decommissioning old equipment, and upgrading existing equipment to modernize capabilities.
- Improving the user proposal submission, review, and allocation process for better usability and coordination with other BNL facilities;
- Implementing a "cradle to grave" materials safety concept, placing equally high emphasis on nanomaterials and chemical safety from project inception, through project execution, to final material disposal.

4.2 Expert Staff

Maintaining a diverse group of the highest-quality scientific, technical, and administrative staff is central to fulfilling the CFN mission. CFN cultivates a positive culture where all voices are heard, through a set of overlapping communication practices that reduce barriers between staff and management. Key components of the CFN strategy include:

- Recruiting, developing, and retaining a diverse workforce of the most talented professionals at all levels;
- Creating a positive, inclusive work environment by promoting collaboration and fairness;
- Practicing transparent, meaningful two-way communication;

- Nurturing professional development through thoughtful mentoring for staff members at all career stages, and toward appropriately balanced science and user support efforts;
- Seeking internal and external recognitions for staff professional achievements;
- Maintaining vibrant postdoctoral researcher and graduate student programs;
- Fostering an environment in which scientific staff engage with external research opportunities, especially those connected to national science initiatives.

4.3 Engaged User Community

To fulfill its mission of serving a satisfied and productive user community, the CFN continuously engages past and current users and actively seeks communities of new users. The CFN strives to identify and eliminate barriers hindering user research, to support the broadest community of users more effectively, through activities that include:

- Engaging early career scientists to maintain the vibrancy of the user program, deliver frontier research that encompasses the most forward-looking knowledge, and develop the next generation of nanoscience researchers;
- Fostering transparency and cooperation through an engaged Users' Executive Committee (UEC). The CFN UEC provides an organized framework for communicating user needs to CFN and BNL management. Together, NSLS-II and CFN UECs organize the annual Users' Meeting, with support from CFN staff. The CFN regularly engages the UEC for input on how to best support a diverse user community.
- Enhancing the User Experience. The CFN strives to optimize the user experience, from proposal submission and review/allocation, instrument scheduling, data collection, and dissemination of research findings.
- Engaging in Strategic Partnerships. CFN staff engage with user teams when there is a clear alignment of scientific interests, including with Energy Research Frontier Centers (EFRC) and Small Business Innovation Research (SBIR) projects.
- Reaching New Users. CFN is working to expand the breadth of users by deploying staff as ambassadors at scientific meetings and conferences, and targeting university engagement strategically.
- Providing Technical Workshops. Instrument/technique training and user development workshops, in-person or virtual/recorded, serve as effective outreach to expand the user community and strengthen engagement.

4.4 State-of-the-art Facilities

CFN facilities are designed with the entire materials research workflow in mind, providing users with an integrated set of tools for a complete research experience under one roof. To that end, we develop and operate advanced instrumentation in materials synthesis, nanofabrication, electron and photon probes, and computational resources with software tools for theory, simulation, and data analytics.

The CFN portfolio is strategically refreshed to provide cutting-edge facilities attractive to high-impact users. We balance upgrading existing major capabilities with acquiring key new instruments. We research, design, and build novel nanoscience facilities that are unique in the world, including integrating advanced analytics and AI/ML tools. Our facility plans are driven by the needs and trends in major materials research initiatives.

Materials Synthesis and Nanofabrication

CFN will make significant investments in the nanofabrication facility to enable more sophisticated research, with a particular focus on microelectronics fabrication:

- *Electron-beam Lithography*: State-of-the-art, 200kV electron-beam lithography system optimized to support a broad range of research. Improved writing speeds of >100MHz will facilitate high throughput exposures and large area patterning (cm^2 or larger) critical for many applications including synchrotron experiments and combinatorial studies.
- *Direct Write Laser Lithography*: Maskless photolithography via a rastered, focused UV laser beam provides great flexibility and patterning arbitrary designs with micron-scale critical dimensions.
- *Combinatorial Thin Film Deposition*: State-of-the-art physical vapor deposition tool will expand the range and complexity of materials synthesis, by providing co-sputtering, reactive sputtering, and compositional gradient films.
- *EUV Interference Lithography*: Synchrotron instrument for interference lithography at the EUV wavelength (13.5 nm) used in the state-of-the-art lithography tools. This capability will enable research on novel patterning materials and methods for Angstrom-era nanofabrication, which is critical to advancing the semiconductor industry. The platform will serve as open infrastructure for the U.S. microelectronics R&D community, addressing the urgent bottleneck in evaluating new EUV materials.

Liquid-handling robot upgrade: The CFN has established a liquid-handling robotic platform for automated synthesis-by-assembly of multicomponent systems including nanoparticle-based materials, DNA structures, and designed biomaterials. An upgrade to this system will incorporate in-line characterization and AI/ML guided feedback control.

Electron and Photon Probes

IP-QM: The CFN Integrate Platform for Quantum nanoMaterials (IP-QM) will offer precise assembly, processing, and multimodal characterization of heterostructure quantum materials. Providing a unique set of complementary cryo-probes, IP-QM will facilitate transfer of materials and analysis of the same feature across the suite:

- Atomic layer etching of 2D and quasi-2D materials, providing atomically precise control over material thickness.
- Cryogenic upgrade to the combined aberration-corrected low-energy electron microscope & photoemission electron microscope (AC-LEEM/XPEEM) operated at NSLS-II will enable cryogenic operation.
- Multimodal cryogenic scanning microscope with integrated quantum sensors will provide a testbed for quantum methods of sub-nm electrometry, magnetometry & spectroscopy.
- A cryogenic, ultrafast pump-probe magneto-optical microscope, realized by coupling a new cryostat/magnet assembly with an existing ultrafast pump-probe microscope.

MilliKelvin Multiprobe: This unique scanning probe microscope, as an expansion of IP-QM, will perform multimodal ultrahigh-sensitivity measurements at millikelvin temperatures, correlating spatial changes in magnetic, electronic, and dielectric properties. Given the large size of devices like superconducting qubits, probes will be engineered with a sensor area of several square microns.

Low-Voltage scanning transmission electron microscope (*STEM):* A state-of-art STEM for high-resolution studies of electron-beam sensitive materials will have an ultra-bright, cold field-emission gun with aberration correction and monochromator for atomic resolution imaging at low voltage and low electron dose, with state-of-the-art <5 meV electron energy loss spectroscopy (EELS) resolution. This instrument will be equipped with secondary electron detectors for surface imaging at the atomic scale above and below the sample, laser with line of site to the sample allows for in situ heating and cleaning, and a leak valve for in situ experiments near UHV conditions.

Ultrafast Camera for ETEM: In collaboration with the Molecular Foundry (Lawrence Berkeley Laboratory), and Computing and Data Sciences (BNL), we are deploying a unique, ultrafast direct electron detector attached to the Titan aberration-corrected ETEM. This will enable image capture at 87,000 frames per second — a first-of-its-kind capability for atomic-scale, operando studies of material dynamics on microsecond timescales. AI/ML methods will be integrated to denoise and accelerate image analytics.

UHV E-STEM: A first-of-its-kind monochromated aberration-corrected UHV environmental scanning transmission electron microscope (E-STEM). This instrument will allow for gaseous environments at the sample from UHV to 10 Torr (spanning 9 orders-of-magnitude) for in situ/operando experiments with state-of-the art spectral resolution (<5meV) at the atomic scale. A vacuum transfer holder for air-sensitive materials and a double-tilt heating holder for in situ annealing are available.

High-resolution TEM/STEM: A 200kV transmission /scanning transmission electron microscope (TEM/STEM) for high-resolution structural and analytical characterizations. This TEM/STEM will be equipped with an energy-dispersive x-ray and electron energy loss spectrometers for elemental and chemical analysis, and with a camera for a large field of view.

Synchrotron X-ray Scattering: The CFN will continue to invest in the Complex Materials Scattering (CMS) and Soft Matter Interfaces (SMI) beamlines, partner x-ray scattering endstations at NSLS-II. High-throughput and autonomous experimentation will be further developed through advanced software tools and real-time materials processing platforms. The prototype AI assistant interface will be deployed for general users.

HAXPES: A new instrument featuring a multicolor tender x-ray source will enhance CFN lab-based AP-PES capabilities. The variable x-ray energy will provide three sample probing depths, broadening the range of sample environments for AP-PES analysis. The tender x-ray source enables investigations of gas/solid interfaces at 1 atm.

X-ray Tomography: This state-of-the-art x-ray tomography will be capable of x-ray imaging in 2D and 3D with sub 50 nm spatial resolution and with fields-of-view as large as several tens of microns. The instrument will have cells for *in situ* imaging in liquid and gas environments.

Laser Ablation: This state-of-the-art femtosecond laser ablation system will enable large sample processing and microchip imaging through targeted delayering. This tool will operate in concert with non-destructive techniques like x-ray imaging to unveil microstructure and defects.

Laser Upgrade for PEEM: An upgrade to the CFN XPEEEM/LEEM system with a supercontinuum IR-UV laser for pumping electrons from valence to conduction bands while simultaneously probing the electronic structure with XPEEM/LEEM.

Computational Resources

HPC and advanced computing: Innovative software and data management, including use of machine-learning tools and development and applications of physical theory, will be supported by continued CFN investments in on-premises high-performance and high-throughput computing capabilities, data storage, and communications in cooperation with the BNL Scientific Computing and Data Facilities. In parallel, CFN is scoping and piloting cloud-based resources to provide flexible burst capacity and advanced workflows for internal research and, ultimately, user science. CFN will collaborate with BNL partners to develop workload management and automation strategies that orchestrate heterogeneous CPU, GPU, and storage resources across local clusters, leadership-class facilities, and cloud environments. These capabilities will underpin workflows that democratize access to advanced modeling tools and enable high-throughput calculations to generate synthetic datasets for AI/ML training and accelerated nanomaterials discovery. Where appropriate, these workflows will be delivered through web-based tools (e.g., lightshow.ai) that lower barriers for staff and users to engage advanced computing resources.

4.5 Partnerships

Building upon a culture of collaboration and innovation, the CFN will establish and strengthen strategic partnerships to best apply CFN research expertise and capabilities in support of major DOE initiatives, e.g., the BNL-led, Office of Science QIS Center: Co-Design Center for Quantum Advantage (C^2QA) and Energy Frontier Research Centers in areas of national interest. Intellectual property and technology transfer are other ways to connect with industry researchers, such as through the DOE SBIR program and Technology Commercialization Fund. Partner users provide investments of expertise and equipment that help CFN grow in new directions.

The CFN will continue to deepen the relationship with NSLS-II through investments in x-ray nanoscience instrumentation, joint projects, and streamlined access mechanisms (Figure 7):

- Development and management of new x-ray nanoscience instruments and Partner User Agreements with NSLS-II to support users at four endstations. These ventures represent leading capabilities in x-ray scattering, photoelectron spectromicroscopy, and x-ray tomography. CFN contributes essential equipment and staff & helps users access unique experimental capabilities.
- CFN capabilities and expertise are applied to developing new capabilities at NSLS-II. For example, CFN nanofabrication is used to create high-performance x-ray optics, beam sensors, and reference samples for method development at beamlines.
- CFN leads the development of advanced tomographic processing methods for reduced artifacts and noise, while reducing the total dose (x-ray or electron) to sensitive samples.
- The CFN will continue to establish joint projects with NSLS-II staff and users. For example, CFN is making use of the complementary properties of x-rays and electrons to image the same catalyst under realistic operating conditions, to interrogate working photo-electrochemical systems, and for imaging and spectroscopy of soft and hybrid hierarchical systems.
- CFN and NSLS-II are collaborating to develop and implement data analysis & machine learning software for large data sets from synchrotron and electron microscopy experiments.

The CFN partnership with NSLS-II

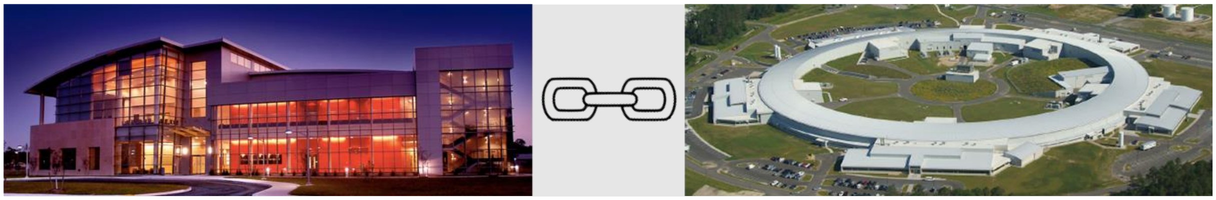

Figure 7. A strong partnership with NSLS-II is a key element of the Strategic Plan. Three illustrative areas are:

Theme 1: Nanomaterial Synthesis by Assembly

The CFN is a world-leader in DNA programmable self-assembly of heterogeneous nanomaterial lattices. CFN is developing methods using the advanced beamlines at NSLS-II to study how self-assembly can be used to organize targeted nanocomponents, especially optically and chemically-active species, into well-defined functional lattices.

Theme 2: Quantum Nanomaterials

CFN and NSLS-II provide complementary capabilities for advancing the understanding of quantum nanomaterials, including superconducting films, 2D materials and heterostructures, and correlated systems. Synchrotron-based x-ray scattering, spectroscopy, and photoemission microscopy techniques available at NSLS-II are key resources for studying the structural, chemical, and electronic properties of these materials.

Theme 3: AI-Accelerated Nanomaterial Discovery

CFN deploys AI/ML methods at NSLS-II beamlines. Machine-learning methods have been created to automatically analyze x-ray scattering and spectroscopy data. Algorithms for autonomous experiment control have been developed in collaboration with the DOE CAMERA project. A prototype AI assistant for synchrotron beamline control is in use at x-ray scattering endstations.

Theme 4: Multimodal Analysis of Nanomaterials in Operando Conditions

CFN and NSLS-II staff operate a low energy electron/x-ray photo-electron emission microscope (LEEM/XPEEM) endstation, and have implemented cells and data analytics for hard x-ray absorption spectroscopy (XAS) at NSLS-II. Combining information from operando experiments at NSLS-II endstations and the CFN environmental transmission electron microscope (E-TEM) coupled to a suite of in-situ and multimodal sample holders, critical information from dynamic processes can be interrogated.

The CFN partnership with C2QA

Figure 8. A strong partnership with C2QA is a key element of the Strategic Plan. Three illustrative areas are:

Theme 2: AI-Accelerated Nanomaterial Discovery

CFN and C2QA will collaborate on developing autonomous experimentation and data-analytics methods for quantum materials and devices characterization. Machine-learning algorithms created at the CFN will be adapted to automatically collect and analyze spectroscopy data, improving experimental bandwidth and throughput.

Theme 3: Quantum Nanomaterials

CFN quantum materials capabilities are well aligned with the C2QA's goal of discovering and understanding materials that enable scalable quantum technologies. Synergy between the CFN's millikelvin characterization suite and the C2QA's qubit measurement facility will create a seamless pipeline from quantum materials discovery to device testing.

Theme 4: Multimodal Analysis of Nanomaterials in Operando Conditions

CFN and C2QA are advancing multimodal characterization of quantum materials and devices under realistic, cryogenic operating conditions. These operando studies will provide critical insight into decoherence mechanisms and device-level functionality.

The CFN has provided essential user support to the Co-Design Center for Quantum Advantage (C2QA), a Brookhaven-led National Quantum Information Science Research Center (NQISRC), since its establishment in 2020 (Figure 8). CFN will strengthen this partnership by maximizing synergy between the CFN's expertise in quantum nanomaterials fabrication and characterization and C2QA's strengths in qubit design, testing, and performance optimization. Examples of collaborative efforts include:

- The CFN will continue providing user support to the C2QA, enabling access to CFN facilities and expertise in nanomaterials fabrication and multimodal or operando characterization to identify and mitigate sources of loss in superconducting qubits, driving further improvements in device performance.
- The C2QA's new superconducting-qubit measurement facility will complement and be closely integrated with the CFN's forthcoming millikelvin characterization suite, creating a seamless pipeline from quantum materials discovery to device testing. Scientists from both centers will collaborate to establish this shared millikelvin research facility in the adjacent ISB facilities.
- The C2QA and CFN will collaborate on developing autonomous experimentation methods to enhance the data-collection bandwidth of qubit measurements, applying CFN's machine-learning techniques for automated acquisition and analysis of spectroscopy data.

5. METRICS & RESOURCES

5.1 Metrics

Our measure of success is the extent to which the CFN supports a community of users and staff renowned for nanoscience breakthroughs and national impact. Each year, CFN reports progress to DOE through the Performance Evaluation and Measurement Plan (PEMP). The DOE evaluates CFN facility operations with external reviewers assessing the impact of internal research and user science, user satisfaction, and efficiency of facility operations. The CFN management team, supported by the external CFN Science Advisory Committee (SAC), continually assesses progress.

Internally, we measure progress in mission-critical areas using trackable metrics:

- Operating a world-class nanoscience user facility. We assess instrument performance and availability, user satisfaction, and tangible output (especially peer-reviewed journal publications).
- Developing unique capabilities for the user community. We assess our existing, new, and future capabilities; comparing to national priorities, requests from the user community, and CFN research plans. We solicit feedback from users regarding satisfaction with capabilities and support.
- Fostering the success of world-class scientific staff. We assess staff through tangible impact (publications, citations) and recognition (leadership positions, awards, peer recommendations). We track contributions to intellectual property.
- Being an essential resource for collaborative research. We assess involvement in multidisciplinary research partnerships with academia, other national laboratories, and industry. We consider whether CFN involvement is ancillary, or core to the work.

5.2 Resources

Guided by user feedback, input from the UEC, and advice from the SAC, the CFN allocates resources (equipment, staff, operating funds) to support each facility and ensure that high-impact research is carried out in service of identified national priorities. CFN operations are funded by a block grant from the DOE Office of Science. From this budget, the CFN targets investing at least 10% each year in new scientific equipment. Projecting realistic future budget increases based on past history, the CFN anticipates being able to carry out this plan over the five-year period described here.

Fullest impact and utilization of the capabilities developed in the scope of this plan will require the CFN to add scientific staff in strategic areas. Additional operations funding, beyond budget projections, will further enhance unique CFN capabilities.

If resources are more limited in the future, the CFN will adjust the scope of this plan accordingly and adopt a conservative approach toward hiring additional staff. In such a scenario, the CFN will establish priorities based on progress among the scientific themes, growth of high-impact facility usage, and input from the SAC and the user community, to ensure that the CFN fulfills its core mission and continues to thrive.